Currency Features for Visually Impaired People

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ABSTRACT

The estimated 3.7 million Americans with low vision experience a uniquely difficult task in identifying the denominations of U.S. banknotes because the notes are remarkably uniform in size, color, and general design. The National Research Council's Committee on Currency Features Usable by the Visually Impaired assessed features that could be used by people who are visually disabled to distinguish currency from other documents and to denominate and authenticate banknotes using available technology.

Variation of length and height, introduction of large numerals on a uniform, high-contrast background, use of different colors for each of the six denominations printed, and the introduction of overt denomination codes that could lead to development of effective, low-cost devices for examining banknotes were all deemed features available now. Issues affecting performance, including the science of visual and tactile perception, were addressed for these features, as well as for those features requiring additional research and development. In this group the committee included durable tactile features such as those printed with transparent ink, and the production of currency with holes to indicate denomination. Among long-range approaches considered were the development of technologically advanced devices and smart money.

Key Words: Currency features, visually impaired people, denomination

1. INTRODUCTION

There are an estimated 3.7 million people in the United States who are visually disabled, i.e., who have visual acuity no better than 20/70 in the better eye or who have a maximum visual field of no more than 30 degrees.[1,2] About 200,000 of these people are blind. An additional 9 million Americans live with other, milder forms of visual impairment.

U.S. citizens with low vision experience a uniquely difficult task in that U.S. banknotes are remarkably uniform in size, color, and general design. The U.S. Treasury's Bureau of Engraving and Printing recognized that the redesign of the currency, with introduction of a new $100 bill beginning in 1996, presented an opportunity to introduce features that would make U.S. banknotes more readily usable by visually impaired people. Features that would improve the ability of people who are blind or who have low vision to easily denominate U.S. banknotes would benefit a much wider population of people with milder forms of visual impairment and people with normal vision in low light situations.

A National Research Council Committee on Currency Features Usable by the Visually Impaired was charged to assess features that could be used by people who are visually disabled to recognize currency from other documents and to denominate and authenticate banknotes using available technology.[3] It also was asked to identify research needs, in particular promising areas that could lead to attractive future approaches. Features were grouped as those available now; those requiring some additional research and development; and those that represented long-term research and development opportunities. To evaluate implementation potential of the various features proposed, the committee considered how well the

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feature could be produced using current U.S. banknote printing technologies, including intaglio printing and the security paper substrate.

Key objectives of currency identification include accuracy, speed, and confidentiality across a wide range of lighting conditions and for both new and worn bills. Under all conditions, users would like to have fast and nearly effortless transactions; features that slow down transactions, such as the need for specialized equipment, or features that require extended effort or scrutiny run counter to this objective. The goal of the committee was to identify features that could be incorporated into U.S. banknotes that would allow everyone to use them without requiring outside aid. A benchmark of the effectiveness of currency features is to make banknotes as identifiable as coinage. Coins use a combination of size, weight, color, and edge texture, making them identifiable by both touch and by vision.

2. VISUAL IMPAIRMENT

There are a variety of ways to define visual impairment. The committee relied primarily on the terms "visual disability," "low vision," and "blindness."[*] "Visually disabled" refers to those who are blind or have low vision. In the U.S. there are approximately 200,000 people who are blind; they have no useful pattern vision, but some may retain light perception.[1,2] The remaining people in the visually disabled category are said to have low vision, often defined as best-corrected letter acuity less than 20/60[†] in the better eye[4] or the inability to read regular newsprint with optimal reading glasses. Some people with severe peripheral field loss are classified as having low vision even though their letter acuity may be higher than the 20/60 criterion. According to Genensky,[1,2] there are approximately 3.7 million visually disabled people in the U.S. Figure 1 shows the rates of occurrence of visual disabilities and blindness by age group in 1990 within the U.S. Low vision in this figure is defined as visual acuity no better than 20/70 or visual field less than 30 degrees.

Age-related macular degeneration is the leading cause of low vision. Loss of vision in the high-resolution central portion of the visual field causes individuals with macular degeneration to rely on their low-resolution peripheral vision. Some diseases, such as glaucoma or retinitis pigmentosa, can result in the loss of almost all peripheral vision. With only a small island of central vision remaining, individuals with this type of impairment may retain fairly high acuity, but will experience difficulty in visual search tasks such as finding signs or locating numbers in the corners of banknotes. Other diseases, such as diabetic retinopathy, can result in patchy vision loss across the visual field. Figure 2 illustrates the effects of various visual disabilities compared to normal vision.

Another type of visual disability is reduced contrast sensitivity. Many types of eye disease, such as cataract, can cause a reduction in retinal image contrast or a decrease in sensitivity to contrast by retinal neurons. The consequence is an effective decrease in the difference between light areas and dark areas of an image. People with normal vision have a high tolerance of loss in contrast. For example, in reading, print contrast can be as low as 10% before there is an effect on reading speed for people with normal vision.[5] For people with low vision, however, even small reductions in print contrast can adversely affect reading.[6] Figure 3 demonstrates the visual effects of loss of contrast sensitivity.

For currency design, each of these classes of visual disability will require a different approach. For people who have low visual acuity, including large numerals will improve their ability to denominate banknotes. The large corner digits on the portrait side of the $1 and $10 U.S. banknotes would be at the visual limit for someone with 20/400 letter acuity when viewed at a normal reading distance of 16 inches. At a viewing distance of 40 inches, roughly the distance from the eye to a banknote on a checkout counter, these numerals are at or beyond the acuity limit of about 20/160. Identification at the acuity limit is slow and requires optimal viewing conditions, including flood lighting and 100 percent black-white numeral contrast, which is not even true of crisp, new banknotes. Only people with visual acuity better than 20/80 would be likely to be able to identify the denomination of a banknote on a checkout counter.

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[*] "Legal blindness" is commonly defined as a visual acuity n the better eye (with best refractive correction) of no more than 20/200 or a visual field of no more than 20 degrees. Approximately 600,000 - 900,000 persons in the U.S. fall into this category, which is primarily used for legal and official purposes. Visual disability and visual impairment encompass a broader population than legal blindness; blindness encompasses a narrower population.

[†] The level of best-corrected vision at which a person is said to have "low vision" has several definition. Measured levels of 20/60 or 20/70 are commonly used and correspond roughly to the more qualitative definition of inability to read regular newsprint. The definition used by each source of the data cited is given with that data.

For people with reduced contrast sensitivity, placing denomination numerals on a plain background that has a high contrast to the numeral itself will improve the ability to denominate banknotes. On a new banknote, the contrast of the corner digits of the portrait side of the note has been measured to be about 60 percent. Worn banknotes can have contrasts as low as 30 percent, and are a challenge to anyone for whom contrast values of less than 100 percent cause difficulty in reading.

3. DISCRIMINATION VERSUS ABSOLUTE JUDGMENT

Determining the denomination of a specific banknote requires that the user distinguish between that banknote and any other denomination. Discrimination refers to the ability to compare two or more objects and tell them apart. In the case of banknote identification, the comparison may be between two banknotes, based on design or size, for example, or between the banknote and a measuring gauge.

A second kind of perceptual judgment, called absolute judgment, may be more applicable to currency identification. Absolute judgment refers to the ability to identify any one of N distinct values when it is presented on its own. Research has shown that when there is a single stimulus, such as length or weight, people can be quite accurate in absolute judgment as long as the number of choices (N) is four or fewer.[7] When N is greater than four, people begin to make mistakes, and require a second clue to improve their ability to identify correctly one of a series when presented on its own. The key point for currency identification is that accuracy of identification will be improved if two or more independent stimuli are used for coding, for example, length and color, or diameter and edge profile as used for coinage. Table 1 shows the variety of cues for successive sizes of U.S. coins.

Coin Value	Coin Diameter (mm)	Change in Diameter in mm (%) from the Next Smaller Coin	Visual and Tactile Differences from the Next Smaller Coin
10 ¢	17.9	—	—
1 ¢	19.0	1.1 (+6%)	diameter, color, edge texture
5 ¢	21.2	2.2 (+12%)	diameter, color
25 ¢	24.3	3.1 (+15%)	diameter, edge texture
$1 (Susan B. Anthony)	26.3	2.0 (+8%)	diameter

4. FEATURES USED IN NON-U.S. BANKNOTES

Many features that can be used by visually impaired people to discriminate among banknote denominations are already incorporated in the designs and production of banknotes worldwide. The committee reviewed the currencies of 171 issuing authorities worldwide. The range of features that can be use by visually impaired people to denominate banknotes included: variable size, variable color, large numerals, special shaped patterns, raised tactile markings printed using transparent or visible ink, watermark features, and machine-identifiable features.

Over 100 of these issuing authorities issue banknotes whose size varies with denomination, which can be used by people with any degree of visual disability to distinguish between the denominations. All but two of those surveyed used different colors for different denominations, which, with appropriate use and choice of colors, can be distinguished by people with very low vision. Twenty-four of the issuing authorities have specifically incorporated large numerals to increase the visibility for people with low vision, for example, the Canadian $20 bill. Another twenty-four have provided tactile features on at least some of the denominations issued, some using printed symbols, either visible or printed with transparent ink such as those on banknotes from the Netherlands, and some using watermarks with exaggerated relief such as those found on Japanese banknotes. In addition to these types of features, all of which can be used by a person unaided by devices other than those normally used, such as eyeglasses, most banknotes contain features that can be read by an appropriately designed machine. These features are often used for authentication by the central banking authority and the denomination codes are not public. However, a number of issuing authorities included symbols or large color patches with distinctive shapes or locations specifically to enable the design of portable machines to aid people who are visually disabled to denominate their banknotes independently. The Bank of Canada has designed their banknotes to accommodate reading by a portable device.

5. DISCUSSION AND RECOMMENDATIONS

Figure 4 illustrates a number of the features evaluated by the committee. The committee recommended four features to improve the ability of people with visual disabilities and people with normal vision to more easily denominate U.S. banknotes: variation of length and height, introduction of large numerals on a uniform, high-contrast background, use of different colors for each of the six denominations printed, and the introduction of overt denomination codes that could lead to development of effective, low-cost devices for examining banknotes.[‡] The addition of coarse features that would indicate denomination by either shape or location (Figure 4f) were considered to be a variation of and secondary to the large numeral on high-contrast background because there is no logical connection between shape or location and denomination. Each of these features addresses a different segment of the population, with size being the only feature that could be used by blind people to denominate banknotes without the use of devices.

All people would be able to use a size clue to denominate a banknote. Although the committee did not identify any technical literature reporting the results of psychophysical measurements on size discrimination and identification in a context directly applicable to currency, the European Blind Union[8] recommends a minimum difference of 5mm between successive denominations. With the addition of a second denomination cue, size differences smaller than 5mm might be effective.

Large numerals could be used by most people who are not blind; if the numeral height were 60 percent of that of the current U.S. banknotes, they would be identifiable by people with visual acuity as low as 20/1000 at a distance of 16 inches. (This identification limit assumes that the numeral is on a plain, high-contrast background.) People with vision lower than 20/1000, who would not be able to read these numerals, would be able to use a color cue. Effective, low-cost devices for denominating banknotes, made available due to the presence of a denomination code on the banknotes, could be used by people who are not able to take advantage of the other features recommended.

The new $100 U.S. banknote has incorporated a dark numeral 100 in the lower right-hand corner, printed in the plain, unprinted are inside the scrollwork border. Although the numeral is not large, the high contrast with the substrate background improves readability. The new series of banknotes will also have a security thread whose position indicates the denomination, a feature that could be used as a basis for a denominating device. Other recommended features may be incorporated in lower denomination banknotes.

Each of the features recommended by the committee could be implemented in a variety of ways to improve security or provide additional denomination information. For example, size can be changed along a single dimension, such as making higher denominations longer, or by changing both banknote length and height. Correlating larger physical size with higher denomination prevents raising, where ink is bleached from a low denomination note, which is then reprinted with a higher denomination design.

Banknotes might contain a single large numeral on a plain, high contrast background, which would help people to correctly orient the banknote, or the design may allow for a large numeral on each face of the banknote. Large numerals might be designed with fine engraving inside or with fine edge detail such as seen in the current banknotes around the Treasury and Federal Reserve Bank seals. These fine details would be not be obvious to a person with low vision, but might be effective in preventing banknote copying with color xerography.

Color could be applied to an entire face of the banknote, as is done for the back of current U.S. banknotes, which are printed in green ink. Color could also be applied in patches in a specified location on the note. The size of these patches should be approximately the same as the recommended size of the numerals so that people with low vision could easily locate and identify them. Changing the shape of the patch, or moving the location of the patch with denomination would add a second denomination cue.

[‡] The inclusion of denomination codes was a lower priority committee recommendation because, although it is recognized that some people will require the assistance of a device, the necessity for such use runs counter to the key objective that everyone should be able to use currency without the aid of devices other than everyday aids such as eyeglasses or hearing aids. Therefore, this solution was not considered to be sufficient by itself.

Although raised tactile markings are an attractive solution for people with visual impairments, the committee did not recommend that they be incorporated in U.S. banknotes at this time. Most research in tactile character recognition has concentrated on Braille printing, where the symbols are approximately 400 microns above the surrounding flat substrate. With intaglio printing, the maximum relief is likely to be approximately 70 microns. Embossed Braille symbols 72 microns high on a stamp produced by the French Post Office were not easily readable by a member of the committee who is proficient in reading Braille, so the committee concluded that relief of 70 microns would not be sufficient to be a reliable denomination indicator. Even if the symbols are readable when the banknotes are first printed, they are not likely to remain distinct after considerable banknote wear. Nevertheless, tactile features potentially offer a variety of ways to assist visually disabled people in denominating banknotes if the durability problem is overcome.

Other features were attractive in concept, but the committee determined that they required additional research and development before they could be recommended for use in U.S. currency. In this group the committee included durable tactile features such as those printed with transparent ink, and the production of currency with holes to indicate denomination. Among long-range approaches considered were the development of technologically advanced devices and smart money.

6. ACKNOWLEDGMENTS

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8. FIGURES

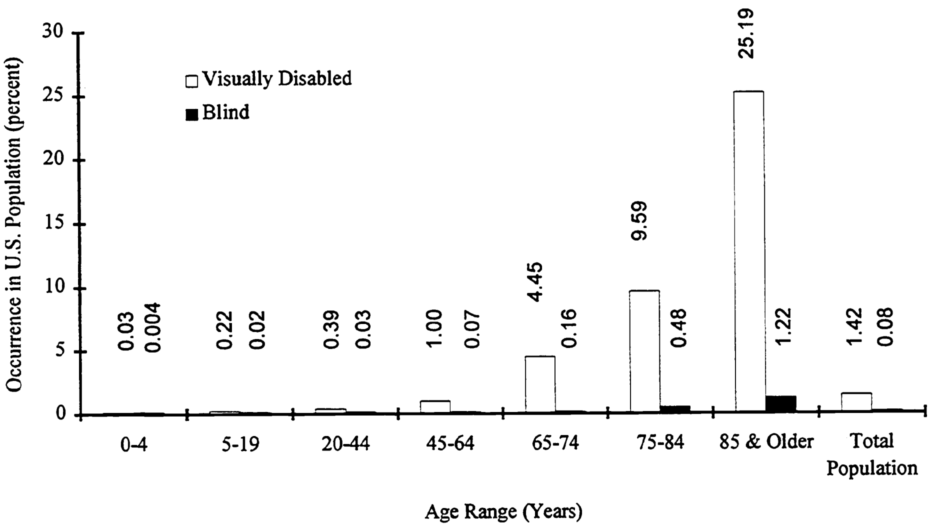


Figure 1 Percentage by age group of 1990 U.S. population with visual disabilities[3] (courtesy of National Academy Press)

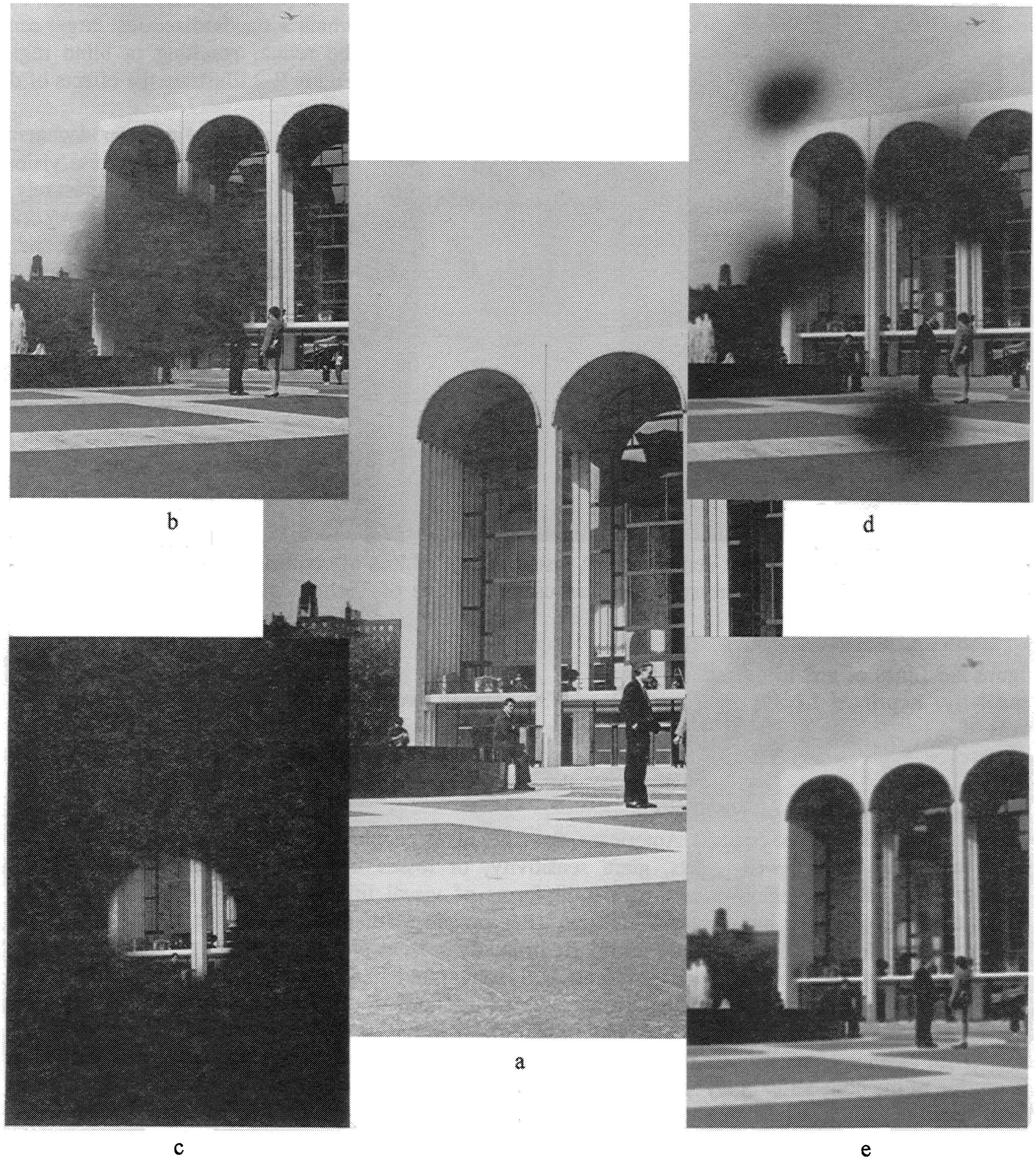


Figure 2 Illustrations of various types of visual impairment using photos of New York's Metropolitan Opera House: (a) normal vision; (b) central field loss; (c) peripheral field loss; (d) patchy vision loss; (e) reduced contrast.[9] (courtesy of The Jewish Guild for the Blind)

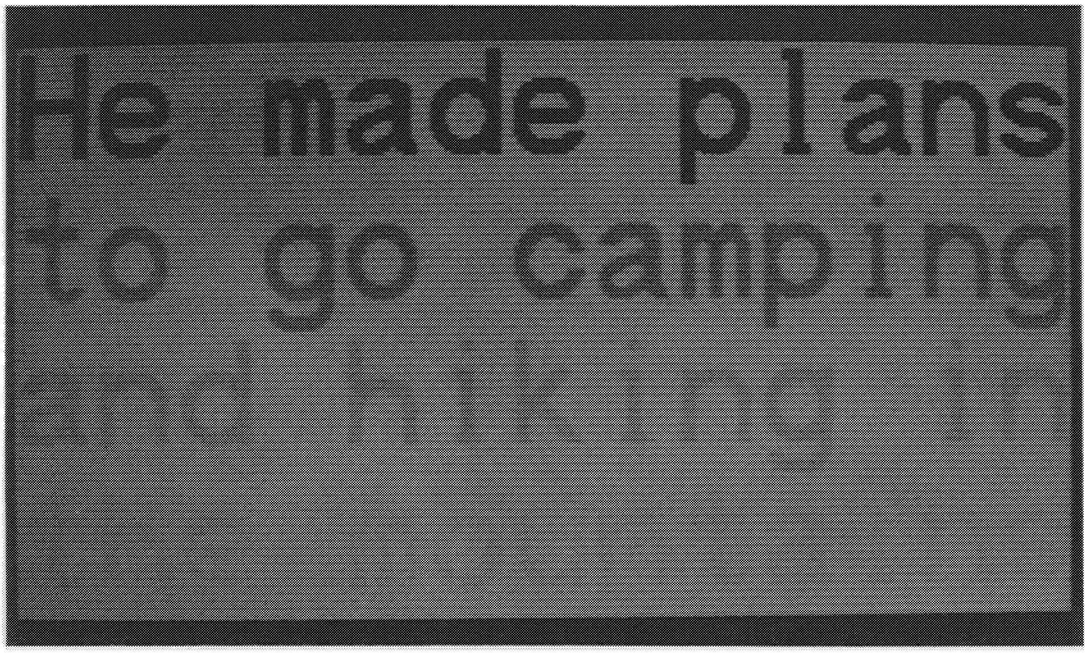
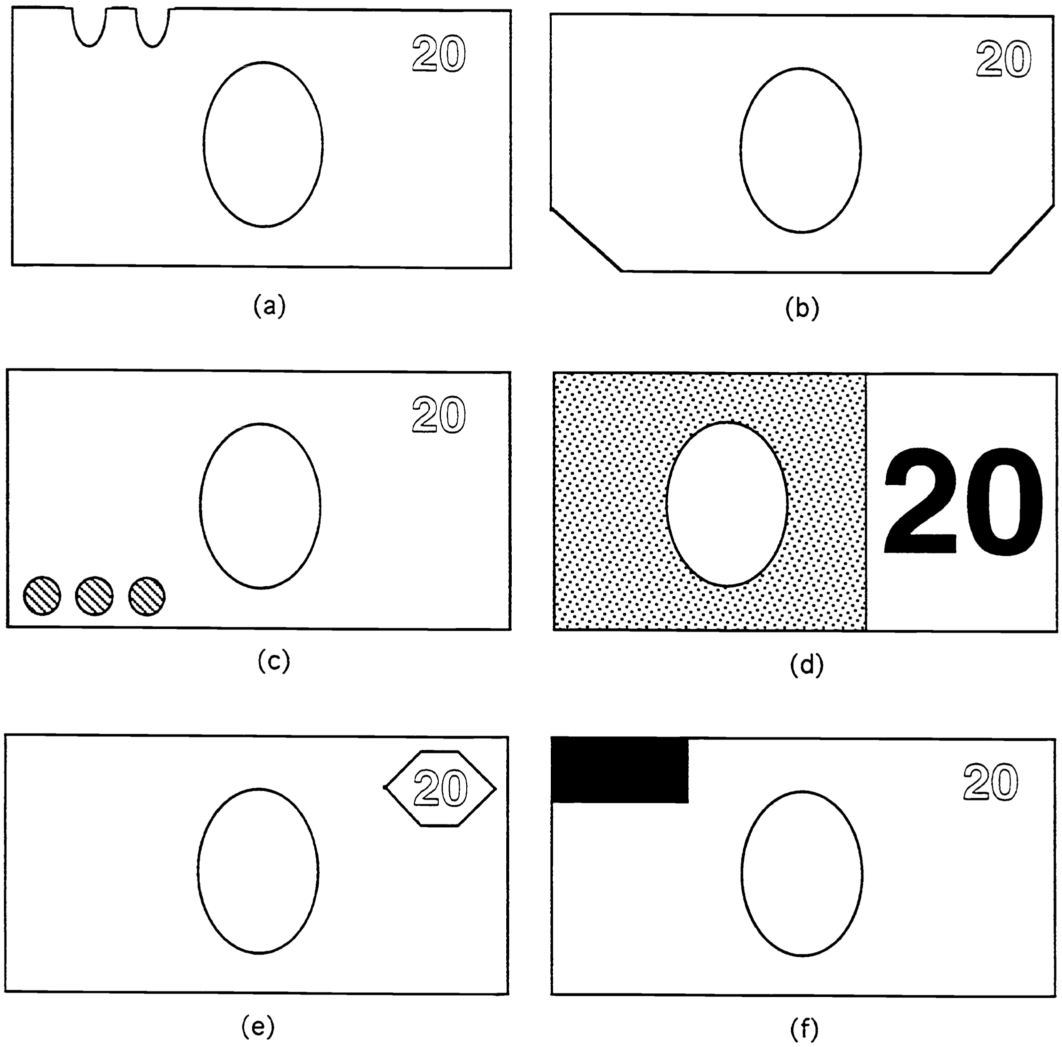


Figure 3 Lines of text in decreasing contrast demonstrating visual effects of loss of contrast sensitivity. "He made plans" (60% contrast); "to go camping" (30% contrast); "and hiking in" (13% contrast); "the mountains" (6.5% contrast).[10] (courtesy of the Massachussetts Institute of Technology Press)



(a) (b)

(c) (d)

(e) (f)

Figure 4 Illustrations of various features evaluated: (a) corner cuts; (b) edge notches; (c) holes; (d) large numerals, uncluttered background; (e) distinctive shapes; (f) coarse patterns. (Features (a) and (b) have been exaggerated for illustration purposes.)[3] (courtesy of National Academy Press)